High-Resolution Ocean and Atmosphere pCO_2 Time-Series Measurements

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PROJECT SUMMARY

Fossil fuel carbon sources and the growth of atmospheric carbon dioxide (CO_2) are reasonably well known based on economic reconstructions and atmospheric monitoring. Global carbon budgets suggest that over decadal timescales the ocean is absorbing, on average, approximately one third of the CO_2 released from human activity. However, the interannual variability in the ocean uptake and variability in the basic regional patterns of the air-sea CO_2 fluxes are poorly known at this time.

Ocean carbon measurements have shown significant biogeochemical variability over a wide range of timescales from sub-diurnal to decadal periods. In situ measurements are also providing a growing body of evidence that episodic phenomena are extremely important causes of variability in CO_2 and related biogeochemical properties. Year-to-year variations in physics (e.g., upwelling, winter mixing, lateral advection), bulk biological production, and ecological shifts (e.g., community structure) can drive significant changes in surface water CO_2, and thus air-sea flux. Changes in large-scale ocean-atmosphere patterns such as El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the North Atlantic Oscillation (NAO) appear to drive much of the interannual variability, and this variability is expressed on regional (several hundred-to-thousands of kilometers) rather than basin-to-global scales. The slower, decadal time-scale ocean responses are not as well characterized as the interannual responses, though there is tantalizing evidence for large-scale biogeochemical regime shifts (or perhaps secular trends) and long-term changes in nutrient and carbon distributions. Distinguishing a human-induced, climate-change signal from natural decadal variability on this timescale is often singularly difficult, particularly given the relatively short duration of most oceanographic data records. But model projections suggest that anthropogenic impacts are accelerating and may become more evident in the near future.

Time-series records are essential for characterizing the natural variability and secular trends in the ocean carbon cycle and for determining the physical and biological mechanisms controlling the system. The biological and chemical responses to natural perturbations (e.g., ENSO, dust deposition events) are particularly important with regard to evaluating potential responses to anthropogenic forcing and for evaluating the prognostic models used in future climate projections. Ship-based time-series measurements are impractical for routinely measuring variability over intervals from a week to a month, they cannot be made during storms or high-sea conditions, and they are too expensive for remote locations. Instrumental advances over the past 15 years have led to autonomous moorings capable of sampling properties of chemical, biological, and physical interest with resolutions as good as a minute and duty cycles of a year or more. Although these new technologies are still underutilized, they have been identified as a critical component of the global ocean observing system for climate.

In 2004, the moored CO_2 program was initiated by the Office of Climate Observations (OCO) as part of the ocean observing system. The moored CO_2 network is still in its infancy, but is quickly expanding into a global network of surface ocean and atmospheric CO_2 observations that will make a substantial contribution to the production of seasonal CO_2 flux maps for the global oceans. The long-term goal of this program is to populate the network of OCEAN Sustained Interdisciplinary Time-series Environment observation System (OceanSITES; http://www.oceansites.org/) so that CO_2 fluxes will

become a standard part of the global flux mooring network. This effort has been endorsed by the OceanSITES science team. The moored CO_2 program directly addresses key element (7) Ocean Carbon Network, as outlined in the Program Plan, but also provides a value added component to elements (3) Tropical Moored Buoys and (6) Ocean Reference Stations. Additional information about the moored CO_2 program can be found at: http://www.pmel.noaa.gov/co2/moorings/.

ACCOMPLISHMENTS

Measurements and Network Development

The moored pCO_2 systems collect CO_2 and O_2 data from surface seawater and marine boundary air every three hours. A summary file with each of the measurements is transmitted and plots of the data are posted to the web once per day. In addition to the moored pCO_2 data collected as part of this project, MBARI has been collecting nutrient and chlorophyll measurements on the 125°W, 140°W, 155°W, 170°W TAO cruises. One person participates on these cruises and analyzes samples from the shipboard uncontaminated seawater supply and from CTD casts performed in-between buoy maintenance. These data have proven to be very helpful at interpreting the buoy based measurements and ultimately trying to examine the mechanisms controlling the observed variability in pCO_2.

In FY07, PMEL/MBARI maintained seven of the sites from FY06, had to relocate one existing site from 170°W, 2°S to 170°W, 2°N and established a new Stratus site in the South Pacific off of Chile (Figure 1). There were a total 12 servicing visits to these sites in FY07. New pCO_2 systems were needed to replace older systems or systems that were lost at sea earlier in the year.

The long term goal of this program is to populate 50 OceanSITES flux reference moorings with pCO_2 systems (Figure 1). With ten moorings currently fitted with pCO_2 systems (including the Papa mooring currently funded by NSF), we are currently at 20% completion of the open ocean moored CO_2 program goal.

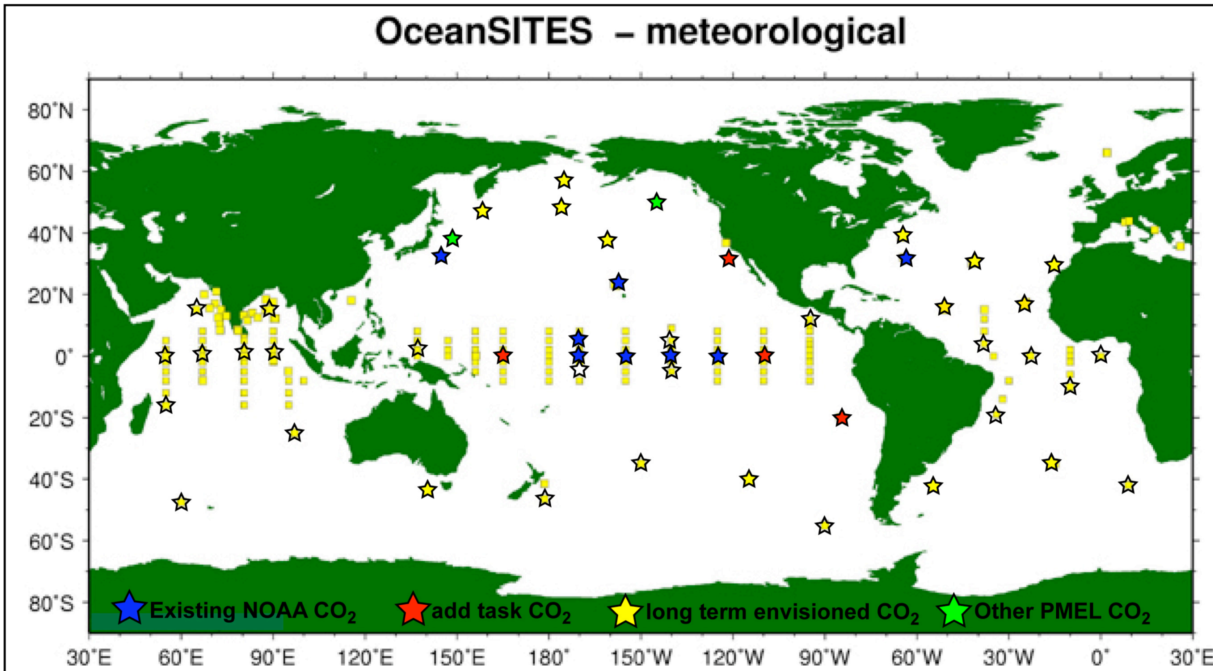

Figure 1. Map of moored pCO_2 systems currently planned and deployed as part of this program.

Instrument/Platform Acquisitions

Here we summarize the deployment schedules and instrument performance over the last year. Systems are grouped into three categories. Five systems are located in the equatorial Pacific on the TAO moorings. Three systems are on Woods Hole buoys located in the North Pacific subtropical gyre, North Atlantic subtropical gyre and in the South Pacific upwelling region off of Chile. Two of the Woods Hole buoys are co-located with shipboard time-series study sites at Hawaii and Bermuda. One system is located off of Japan in a high-latitude buoy operated by Meghan Cronin (PMEL) as part of an OCO funded OceanSITES flux mooring.

***Equatorial Pacific on TAO Moorings**:*

125°W, 0° - At the beginning of FY07, the PMEL built system at this location collected atmospheric measurements, but lacked seawater measurements due to a deployment error, the equilibrator was jammed above the sea surface and was unable to collect seawater measurements until mid-March when the equilibrator broke free. In May, the equilibrator portion of the system was replaced and the system was fully operational until the buoy was damaged and went adrift in July. The system was redeployed in October and is again fully operational. This system is scheduled to be replaced April 2007. The percent data return (only counting times when both seawater and atmospheric measurements were considered good) is as follows, FY07: 32% and Lifetime: 47%.

140°W, 0° - This PMEL-built system was redeployed in late September 2006 and was fully operational until December when the equilibrator was damaged by vandalism. The system continued to collect atmospheric measurements until the system was replaced in May. The system was then fully operational through July when the equilibrator was again damaged. During the September visit to this location, the equilibrator pipe was found bent and jammed, it was straightened by ship's personnel and replaced in the buoy. The buoy is currently fully operational. The percent data return (only counting times when both seawater and atmospheric measurements were considered good) is as follows, FY07: 56% and Lifetime: 56%.

155°W, 0° - This MBARI-built system was serviced in October 2006 but data quality was questionable. We are hopeful that some of these data can be salvaged during the post recovery processing. A new system was deployed in August 2007 and appears to be operating properly. The percent data return is as follows, FY07: 20% and Lifetime: 31%.

170°W, 2°S - This MBARI-built system was serviced in October 2006, but still exhibited intermittent problems throughout the year. In July 2007 a shortage of mooring equipment prevented the redeployment of the CO_2 sensor at this location. Instead, the CO_2 system was deployed at 2°N. The percent data return is as follows, FY07: 56% and Lifetime: 27%.

170°W, 2°N - This MBARI-built system, was deployed at this location for the first time on July 31, 2007. The instrumentation at 2°N, 170°W appears to be working well based on the telemetered data. A full assessment of the data will be possible when the system is returned to the lab. The percent data return is as follows, FY07: 100%, Lifetime: 100%

170°W, 0° - This PMEL-built system was operational until February when the equilibrator was damaged during a vandalism episode in which the buoy was dragged ten nautical miles. The system was replaced in July and continues to be fully operational. The percent data return (only counting times when both seawater and atmospheric measurements were considered good) is as follows, FY07: 50% and Lifetime: 75%.

Nutrient and Chlorophyll - Bottle samples are collected and processed by MBARI personnel from the NOAA ship *Ka'imimoana* on the two occupations of the 155°W and 170°W lines. Approximately 500 samples were collected during the cruises in FY07. Approximately 5% of the samples were discarded due to improper sampling and loss during analysis. The percent data return is as follows, FY07: 95%.

WHOI designed buoys

MOSEAN at Hawaii Ocean Time-series site (158°W, 22°N) – This system was fully operational during the entire period that the buoy was deployed in 2007. The buoy was pulled for service in mid December and was returned to the water late January. The buoy remained in the water through July when it was pulled due to lack of funding for the mooring. The percent data return is as follows, FY07: 100% and Lifetime: 88%.

WHOI Hawaii Ocean Time-series Station (WHOTS) ((157°W, 22°N) – In anticipation of the MOSEAN mooring being pulled due to lack of funding, a new system was deployed in the WHOTS mooring to continue the time series at the HOT site (the two moorings were within a few kilometers of each other). This new system was deployed in June 2007 and is fully operational. The percent data return is as follows, FY07: 100% and Lifetime: 100%.

Bermuda Testbed Mooring (BTM) (64.2°W, 31.7°N) – This system was fully operational during FY07. The mooring was pulled in early March for maintenance and was redeployed in mid-March. The mooring remained in the water through September when it was pulled due to lack of funding for the mooring. The percent data return is as follows, FY07: 100% and Lifetime: 100%.

Stratus (19.7°W, 85.5°N) – This system was deployed in October 2006 and remained fully operational the entire year. This system was recovered and a new system was deployed in October 2007. The percent data return is as follows, FY07: 100% and Lifetime: 100%.

An add task was submitted for this site in FY07, but with the October deployment, we were forced to deploy before we had confirmation that the add task would be funded. Due to budgetary constraints, the add task was not funded but we were already committed to this site. A new add task is being submitted this year to support this work. It is imperative that this add task be funded if we are to continue to maintain this site.

OceanSITES Flux Moorings

Kuroshio Extension Observatory (144.5°E, 32.3°N) – At the beginning of FY07, the system was not operational in due to a problem that occurred during the deployment in May 2006. The mooring was not redeployed until September 2007. A new high latitude mooring was deployed at the KEO site in September and the system is now fully operational.

Japanese Kuroshio Extension Observatory (146.5°E, 38°N) – Since the KEO system was not operational at the time that this new mooring was being deployed in a nearby location, we decided to add a CO_2 system in an effort to begin the data collection in the region. The new mooring was deployed in February 2007 and the pCO_2 system at this site was fully operational during the remaining part of FY07.

Logistical Considerations and Improvements

The pCO_2 systems are mounted in buoys that are deployed from a ship. Currently all of our deployments are in conjunction with another project that is covering the buoy deployment and maintenance costs and has already allocated ship time. The pCO_2 systems are typically sent out on a cruise and are set up and deployed by a member of the scientific party as an ancillary task. This arrangement requires about 4 hours for setup and then approximately 10 additional man hours during the cruise. To keep expenses down we generally request that someone already involved in the cruise be trained to deploy the systems so we do not have to pay to send our people to sea for every deployment. As we have learned over the past year, this approach requires that the systems be very robust. Although we have had some problems this past year with inexperienced people deploying the systems, we still believe that this is the most efficient approach and are striving to make the deployment procedures as simple and fool-proof as possible.

During FY07, upgrades were made to the software to so that the systems can be controlled via satellite by the personnel at PMEL. During every deployment, someone from the PMEL CO_2 group is standing by to remotely turn on the system after the buoy is deployed and to ensure that is running properly before the ship leaves the site. In addition to being able to turn the system on and off, several parameters can be changed remotely to optimize data collection.

During FY06, we had problems with water getting trapped above the equilibrator. Three changes were implemented in the fall of 2006 to prevent this problem from happening in the future and to make the systems more robust. It has taken most of FY07 to implement these changes at all of sites, but the changes have made an obvious improvement. One indicator of success was the fact that our system at BATS was completely operational even though the buoy was flipped upside down during deployment.

The TAO buoys are often the target of fishing and vandalism. The pCO_2 systems on this array have suffered from these acts. In order to get fresh seawater to our equilibrator, the equilibrator pipe extends beneath the bottom deck of the buoy by several inches. On many occasions, the pipe was found bent when it was recovered. It is believed that fishing gear is getting tangled around the equilibrator pipe. We are currently researching options to prevent this from happening.

Biofouling was a bit of problem in FY06 and FY07. The copper content of the equilibrators was increased from 70% to 90% in FY07. A new copper cup was also installed at the bottom of the equilibrator to keep growth to a minimum around the equilibrator. Both of these changes have been beneficial.

Data Processing

All the PMEL summary files are processed and graphed on a website that is updated daily <http://www.pmel.noaa.gov/co2/moorings/>. The data are currently stored at PMEL and are available from Christopher Sabine at PMEL. The MBARI data are available from Francisco Chavez at MBARI. The carbon data management and synthesis teams are in the process of integrating the moored pCO_2

data together with the underway pCO_2 data from a related OCO project. Ultimately all of the surface CO_2 data will feed into the seasonal CO_2 flux map effort that is currently under development.

All systems are thoroughly tested and calibrated over a range of CO_2 concentrations using WMO traceable standard gases in the laboratory before deployment. The systems are then calibrated with a zero and WMO traceable span gas at the beginning of every three hour measurement cycle during the deployment. We have developed a system for processing the moored pCO_2 data that is collected utilizing automated quality control procedures. Based on the calibration, atmosphere, and seawater information as well as other diagnostic measurements for each identified point relative to the surrounding points, the data point may be flagged as questionable or bad. Typically less than 1% of the data are flagged as questionable or bad. To finalize a dataset, the data are compared to any underway pCO_2 data that are available as well as the Marine Boundary Layer (MBL) atmospheric CO_2 concentrations for a given buoy location as provided by NOAA's GLOBALVIEW-CO_2 network. Based on these comparisons and various diagnostics of the automated system calibration information, the entire data set (air and water values) may be adjusted to match these higher accuracy measurements. Typically these adjustments are less than a couple of parts per million. The data are then merged with sea-surface temperature and salinity data collected by other groups on the same buoy. As all data become available, final calibrated data are archived at the Carbon Dioxide Information Analysis Center (CDIAC) and the National Oceanographic Data Center (NODC) on a yearly basis. During the field season it is difficult to keep up with the data processing, but now that the season has ended we are on target to have all the data through March 2007 finalized and submitted to CDIAC for public release by February 2008. We anticipate being able to maintain the one year final data release from the date of recovery for the foreseeable future.

Analysis and Research Highlights

An underway pCO_2 system was recently added to the *R/V Atlantic Explorer*, the research vessel that conducts the time-series work off of Bermuda. Thus, the ship passes very close to the Bermuda Testbed Mooring on at least a monthly basis allowing regular comparisons of the moored and shipboard CO_2 data (Figure 2). An analysis of the moored and shipboard data showed that the two systems agreed to within 0.5 ± 4.7 µatm (n=15,462) when the ship was within 10km of the mooring and the time was within 3 minutes. By comparing data over a range of distances one can begin to assess the correlation length scales for the region. Preliminary analysis at BTM suggests that data are coherent within about 80 km regardless of season.

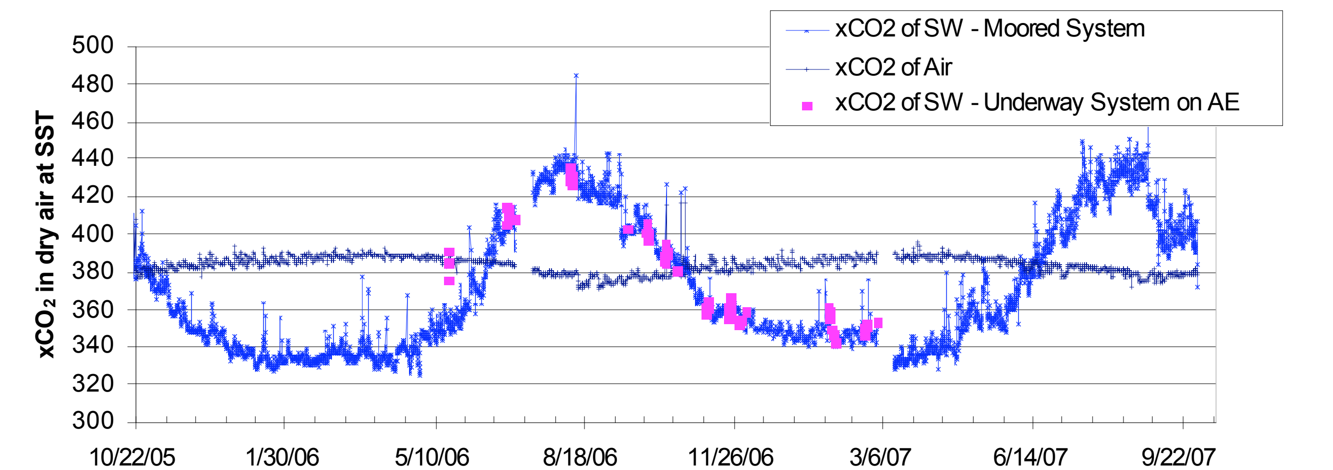

Figure 2. Comparison of time-series CO_2 measurements from the Bermuda mooring and the underway system aboard the R/V Atlantic Explorer.

The addition of new sites in the moored CO_2 network allows the characterization of previously understudied regions. In FY07 the first South Pacific mooring was deployed at the Stratus site off Chile. The first full year of data are shown in Figure 3. These data show that this site is a large source of CO_2 to the atmosphere during the austral summer then drops to about neutral during the winter months. The observed pattern is somewhat different than suggested by the latest Takahashi climatology; but this is not surprising given the lack of data in this region of the world.

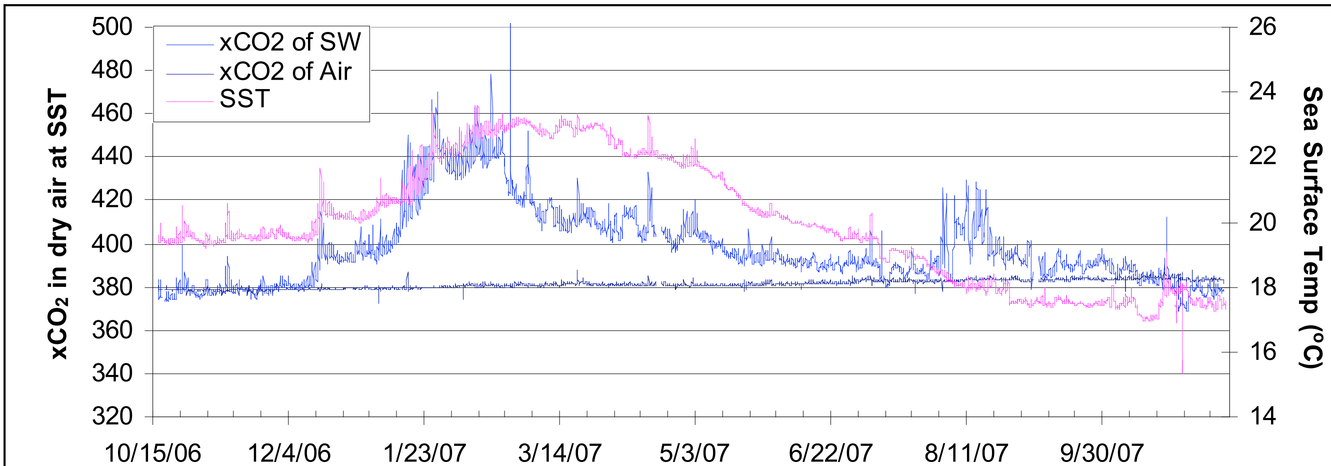

Figure 3. Time-series of CO_2 and sea surface temperature measurements from the South Pacific off of Chile (Stratus mooring).

Due to logistical problems with the moorings at 170°W, the MBARI CO_2 system that is normally deployed at 2°S had to be deployed at 2°N until the next servicing interval. While it is unfortunate that the long time series at 2°S had to be broken, it provides a nice opportunity to study the similarities and differences of the CO_2 system north of the equator relative to south of the equator. Figures 4 and 5 show the latest data from 2°S and 2°N, respectively.

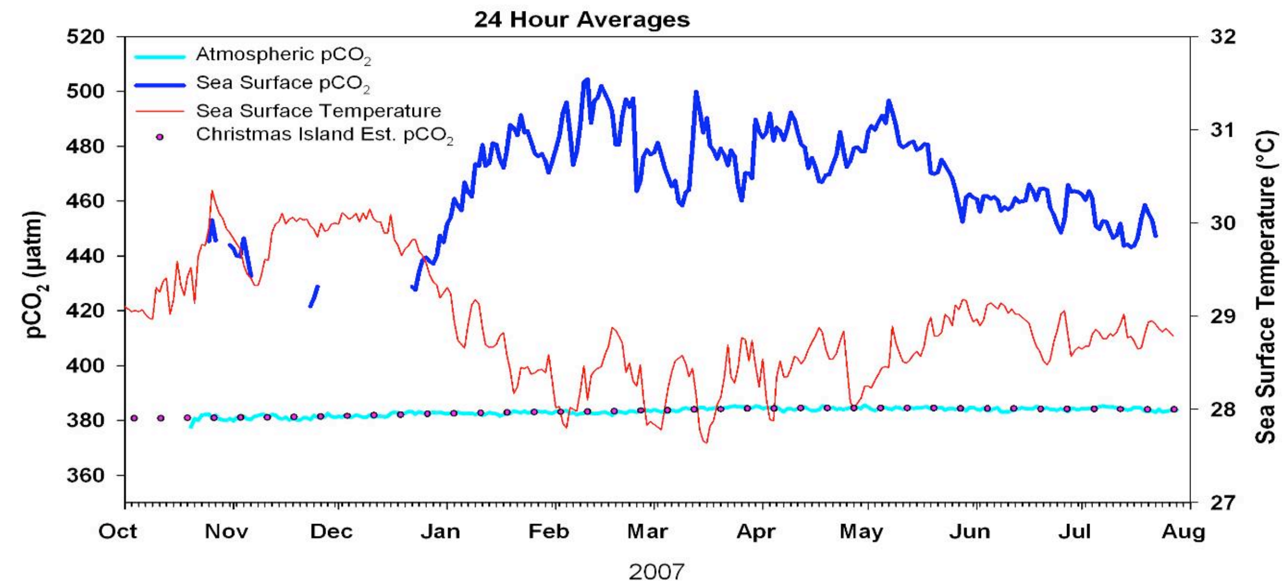

Figure 4. Daily average pCO_2 and temperature at 2°S, 170°W from October 2006 to August 2007.

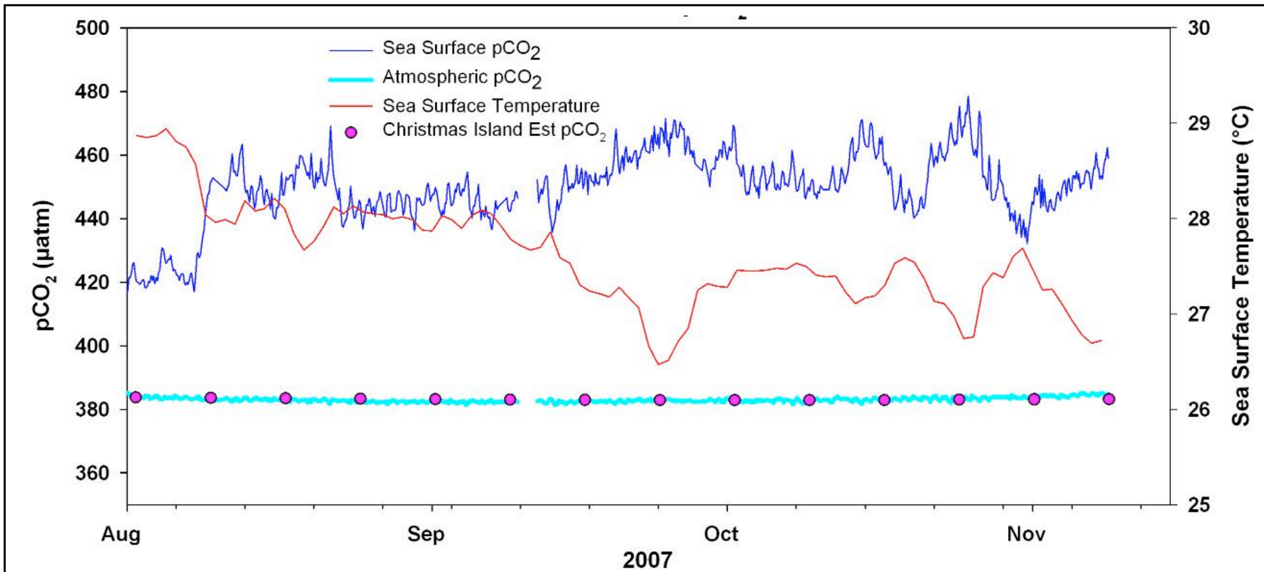

Figure 5. High resolution measurements of pCO_2 and daily average sea surface temperature at 2°N, 170°W from August 2007 to present.

This is the first time that a CO_2 mooring has been located on the northern side of the equatorial upwelling region. The 2°N time series is still too short to evaluate the seasonal differences, but the shorter time scale variability is similar in magnitude and frequency to the 2°S site. The overall magnitude of the air-sea difference is also similar at both sites. What remains to be determined is whether the seasonal trends have the same pattern and whether there is a north-south difference in how the CO_2 system responds to the passage of Kelvin Waves, Tropical Instability Waves, or ENSO events. These data will continue to be examined closely as the times-series grows. Of course the value of time series observations grows as the data sets become longer. The moored time-series program in the equatorial Pacific is among the longest in the world. These data have been able to directly document the increase in surface water CO_2 over time (see figure 6).

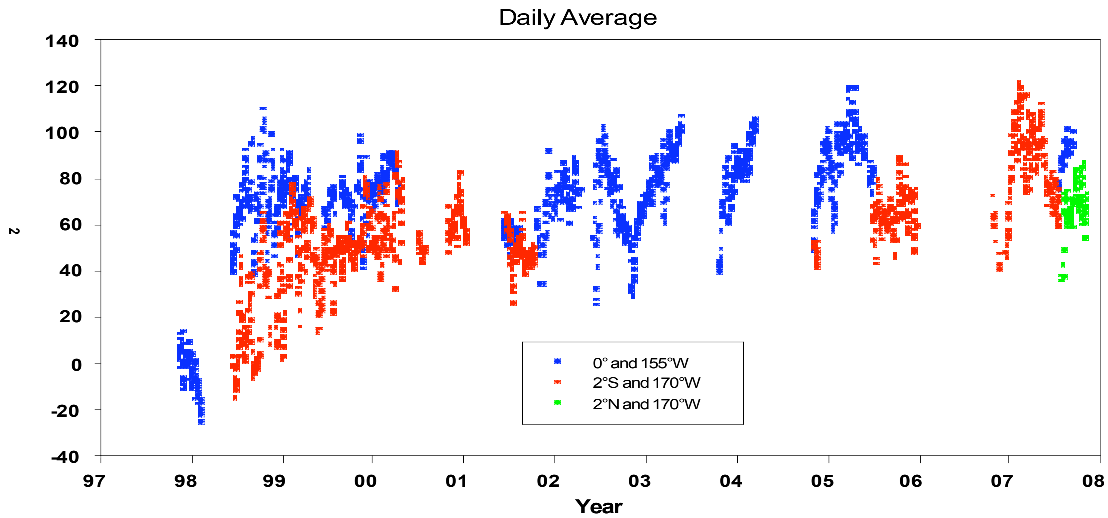

Figure 6. Daily average pCO_2 observations on the equator at 155°W, 2°S, 170°W and 2°N, 170°W from 1997 to present. Even without the '98 El Niño signal there is an apparent increase in pCO_2 over the course of the record.

PUBLICATIONS AND REPORTS

Relevant Publications in FY07

Sabine, C.L., and R.A. Feely (2007) The oceanic sink for carbon dioxide. In Greenhouse Gas Sinks, D. Reay, N. Hewitt, J. Grace, and K. Smith (eds.), CABI Publishing, Oxfordshire, UK.

Sabine, C.L., R.A. Feely, and R. Wanninkhof (2007) 3. Global Oceans; f. Global ocean carbon cycle — in *State of the Climate in 2006*, A. Arguez (ed.).. Bull. Am. Meteorol. Soc., 88 (suppl.)(6), S40–S43.

Birdsey, R.A., R. Cook, S. Denning, P. Griffith, B.E. Law, J. Masek, A.M. Michalak, S. Ogle, D. Ojima, Y. Pan, C.L. Sabine, E. Sheffner, and E.T. Sundquist (2007) Investigators share improved understanding of the North American Carbon Cycle. Eos Trans. AGU, 88(24), doi: 10.1029/2007EO240004.

Lucier, A., M. Palmer, H. Mooney, K. Nadelhoffer, D. Ojima, and F. Chavez (2006) Ecosystems and Climate Change: Research Priorities for the U.S. Climate Change Science Program. Recommendations from the Scientific Community. Special Series No. SS-92-06 of the University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, MD.

Pennington, J.T., Mahoney, K.L., Kuwahara, V.S., Kolber, D.D., Calienes, R., Chavez, F.P. (2006) Primary production in the eastern tropical Pacific: A review. Progress in Oceanography **69**: 285-317.

Montecino, V., P.T. Strub, F. Chavez, A. Thomas, J. Tarazona, and T. Baumgartner (2006) Bio-physical interactions off western South-America. Chapter 10 In The Sea, Volume 14, A. Robinson and K. Brink (eds.), Harvard University Press, Cambridge, Massachussetts, pp. 321-390.

Chai F., M.-S. Jiang, Y. Chao, R. C. Dugdale, F. Chavez, R. T. Barber (2007) Modeling responses of diatom productivity and biogenic silica export to iron enrichment in the equatorial Pacific Ocean, Global Biogeochem. Cycles, 21, GB3S90, doi:10.1029/2006GB002804.

Chavez, F.P., T. Takahashi, W.J. Cai, G. Friederich, B. Hales, R. Wanninkhof, and R.A. Feely (2007) "Coastal Oceans" In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Dilling, L., A. King, D. Fairman, R. Houghton, G. Marland, A. Rose, T. Wilbanks, and G. Zimmerman (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, USA.

Saba, V., J. Spotila, F. P. Chavez, and J. Musick (in press) Bottom-up and climatic forcing on the worldwide populations of leatherback turtles. Ecology.

Freon, P. C. Werner and F.P. Chavez (in press) Conjectures on the influence of climate change on ocean ecosystems dominated by small pelagic fish. In D. Checkley, C. Roy and J. Alheit (Eds). Predicted effects of climate change on SPACC systems. Cambridge University Press.

Invited/Contributed Presentations 2007

Sabine:

CLIVAR Global Synthesis and Observations Panel (GSOP-2) SSG meeting, La Jolla, CA, Dec. 8-9 (invited talk: Global Carbon and Synthesis needs)

JAMSTEC 5-year review of biogeochemical time-series program, Tokyo, Japan, January 17-19, 2007 (invited talk: global carbon time-series)

NACP PI meeting, Colorado Springs, CO, January 22-24, 2007 (invited talk: Carbon Exchanges between the Continental Margins and the Open Ocean; coauthor on 3 posters)

NACP SSG Meeting, Colorado Springs, CO, January 24, 2007

NOAA CO_2 Science Team Meeting, Miami, FL, February 4-7, 2007 (meeting organizer and discussion leader)

Marshall Islands Workshop, Seattle, WA, March 3, 2007 (participated in discussion of ocean acidification issues with Marshall Islanders).

IOCCP SSG meeting, Paris, France, April 10, 2007 (chair of meeting)

Ocean Surface pCO_2 and Vulnerabilities Workshop, Paris, France, April 11-13, 2007 (invited talks: Moorings: New Results and New Technology Overview, Overview of Proxy Techniques for Data Extrapolation and Interpolation)

Anthropogenic Stresses on Ocean Ecosystems Workshop, Seattle, WA, April 23-24, 2007 (breakout discussion leader; invited talk: Existing Technology and Challenges for Monitoring the CO_2 System in Seawater)

Seminar to King County Department of Natural Resources and Parks, Seattle, WA, April 25, 2007 (Ocean CO_2 and its Impact on Marine Ecosystems)

OCB scientific steering committee meeting, Washington DC, May 3-4, 2007.

OCB annual summer workshop, Woods Hole, MA, July 23-26, 2007 (discussion leader for day 2 theme on ocean acidification, organizer of day 3 talks and working group on coastal ocean theme).

OCB scientific steering committee meeting, Woods Hole, MA, July 27, 2007.

NOAA GCC program PI meeting, Silver Spring MD, September 10-11, 2007 (invited talk on moored CO_2 observations).

Chavez:

Invited to workshop to develop Decadal Plans for Research and Calibration/Validation for NASA's Ocean Biology and Biogeochemistry research program, Montreal, Canada, October 7-8, 2006.

Taught 3 day course for Oceans and Climate – SEA Semester Class S-208 - Oceans in the Global Carbon Cycle at Woods Hole, October 21-23, 2006.

Keynote Speaker, Invited by International Oceanographic Commission (UNESCO), at International Seminar on Global Climate Change: Perspectives for Peru, Lima, Peru, October 25-25, 2006.

Organized and Participated in International Conference on the Humboldt Current Ecosystem, Lima, Peru, November 27-December 1, 2006.

Invited Speaker at Round Table Discussion at the Week of the Anchoveta to encourage human consumption rather than fish meal production, Lima, Peru, December 2, 2006.

Invited Participant in Second joint ECO-UP EUR-OCEANS workshop on upwelling systems, Lima, Peru, December 4-6, 2006

Invited Speaker in Hopkins Laboratory of Stanford University Lecture Series on February 9, 2007. Talk entitled "Biological Consequences of Climate Change."

Invited Speaker at AAAS meeting in San Francisco at session on "Informing Management of the Earth's Environment with New Ocean-Observing Systems" on February 17, 2007. Talk was entitled "Designing observing systems to link climate and fisheries."

Participated in an Advisory Group meeting for the National Data Buoy Center (NDBC) in Stennis Space Center, Mississippi on May 24-25, 2007. The primary recommendation of the Advisory Group was the establishment of Science and Technology Teams akin to those put together by NASA for satellite missions.

Invited Speaker at the UC Davis Bodega Marine Laboratory on May 29, 2007 as part of the Synergistic Ocean/Atmosphere/Climate Seminar series.

Delivered a talk entitled "Ocean Ecosystem in a Warmer World" at the International Union of Geodesy and Geophysics meeting in Perugia, Italy on July 5, 2007.

Invited Participant Symposium on "Exploring Ocean Iron Fertilization: the scientific, economic, legal and political basis" Woods Hole Oceanographic, September 26-27, 2007.

Honors and Awards

Chavez appointed to the Graduate Faculty of the University of Maine.

Sabine awarded Department of Commerce Gold Medal Award for pioneering research leading to the discovery of increased acidification in the world's oceans due to the absorption of carbon dioxide.

Public Service

Sabine:

2007-present	member of International Repeat Hydrography Advisory Group
2006-present	member of Ocean Carbon and Biogeochemistry Time-Series Advisory Committee
2005-present	member of PICES section on Carbon and Climate
2005-present	Scientific Steering Committee member for U.S. Ocean Carbon and Biogeochemistry Program
2005-present	Scientific Steering Committee member for U.S. Ocean Carbon and Climate Change Program

2004-present Scientific Steering Committee member for U.S. North American Carbon Program
2004-present Chair of IOC/SCOR International Ocean Carbon Coordination Project (IOCCP)
2003-present Member of the US CLIVAR/CO_2 Repeat Hydrography Oversight Committee

Chavez:
Advisory Committee for Instituto del Mar del Peru (2004-)
Board of Directors, Center for Integrated Marine Technologies (2002-)
Board of Governors, Pacific Coastal Ocean Observing System (2004-)
Science Team for OceanSites (2002-)
Governing Council (Vice-President) Central and Northern California Ocean Observing System (2005-)